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Modeling infrared optical properties of leaves to improve water content estimation

F. Gerber [1, 2], B. Ribeiro da Luz [3], A. Olioso[4] , S. Jacquemoud [1], R. Marion [2] and B. Tanguy [5]

[1] Géophysique spatiale et planétaire, Institut de Physique du Globe de Paris, Paris, France, fgerber@ipgp.fr & jacquemoud@ipgp.fr, [2] Commissariat à l'Énergie Atomique, Bruyères-le-Châtel, France, rodolphe.marion@cea.fr, [3] Spectroscopy Lab, United States Geological Survey, Reston, VA, USA, bribeirodaluz@usgs.gov, [4] Environnement Méditerranéen et Modélisation des Agro-Hydrosystèmes, Institut National de la Recherche Agronomique, Avignon, France, olioso@avignon.inra.fr, [5] Département Optique Théorique et Appliquée, Office National d'Etudes et de Recherches Aérospatiales, Toulouse, France, bernard.tanguy@onecert.fr

Introduction

- Vegetation spectral optical properties in the infrared domain (2.5 – 14 µm) are still poorly known and exploited (Salisbury & Milton, 1988)
- Water mainly absorbs electromagnetic radiation in this domain and its retrieval using imaging spectrometry should be improved
- Vegetation emissivity seems to depend on leaf water status (Olioso et al., 2007)
- Radiative transfer models at leaf (*PROSPECT*) and canopy (*4SAIL*) levels would be useful to understand the radiometric signal at these wavelengths
- Updated measurements of continuous reflectance and transmittance spectra (0.4 – 14 µm) of plant leaves displaying a wide range of water contents are needed

Two independent datasets

	USGS	ONERA
Time and place	June 2008, USGS National Center of Reston (VA)	July 2008, ONERA Research Center of Toulouse (France)
Visible – SWIR spectrometer	Perkin Elmer Lambda 900	ASD FR
MWIR – LWIR spectrometer	Nicolet Nexus 670	Bruker Equinox 55
Dataset	32 leaf samples – 17 species	32 leaf samples – 14 species

For 23 completely dry leaves and 41 fresh leaves including intermediate water contents, we measured:

- directional-hemispherical reflectance *R* and transmittance *T* spectra between 0.4 and 14 µm
- leaf water C_w and dry matter C_m contents (g/cm²)

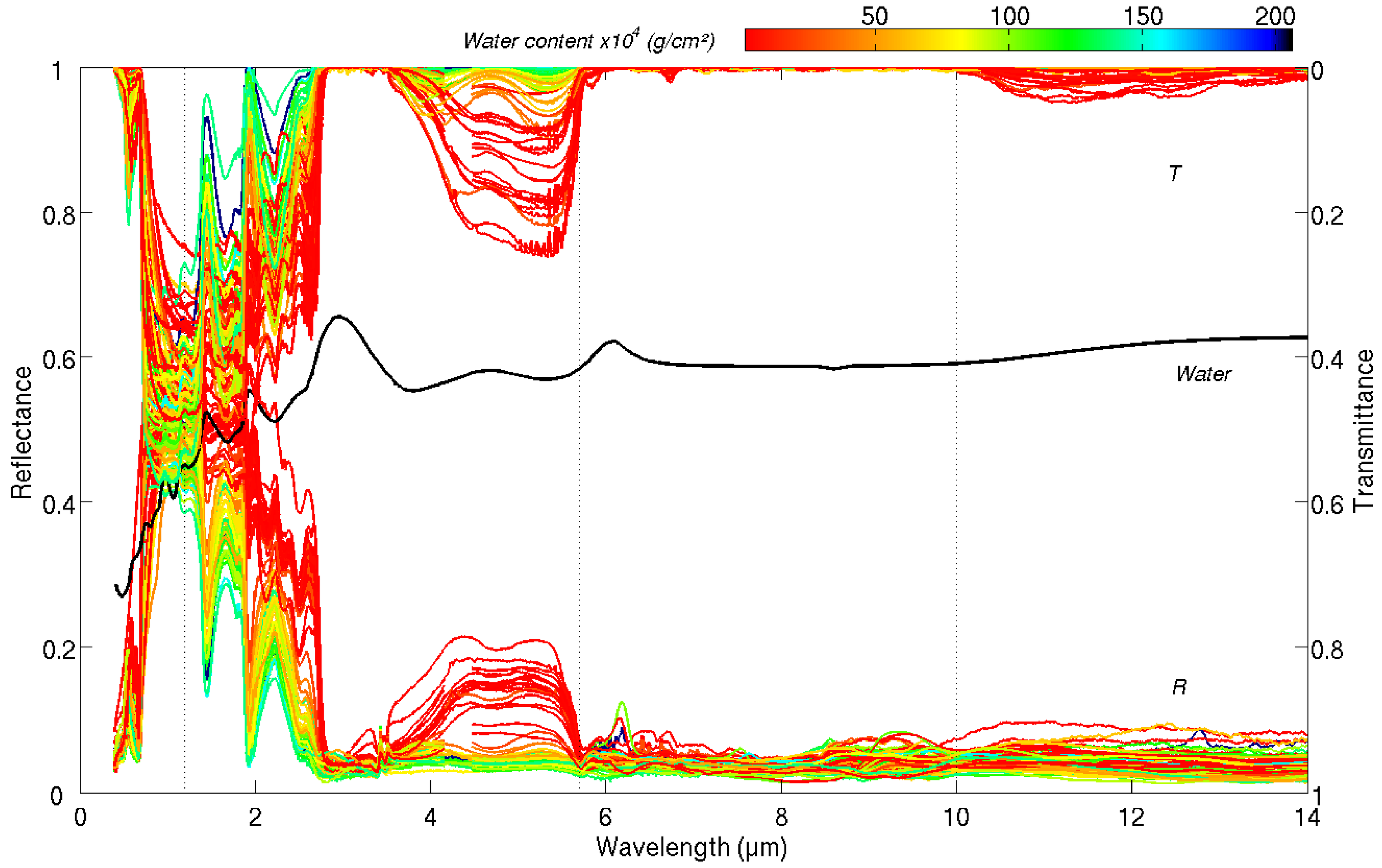

Fig. 1 USGS & ONERA datasets: reflectance and transmittance spectra colored as a function of leaf water content
Specific absorption coefficient of pure liquid water in log scale and arbitrary units

→ 1.2 – 5.7 µm: *R* and *T* are strongly linked to water content

→ 5.7 – 10 µm: *T* is null and *R* ranges from 0.02 to 0.12. *R* is driven by molecular composition and structure of leaf surface in the 8 – 10 µm domain (Ribeiro da Luz & Crowley, 2007)

→ 10 – 14 µm: *R* and *T* are slightly linked to water content

→ Emissivity $\varepsilon = 1-R-T$ ranges from 0.72 to 0.96 in the 2.9 – 5.7 µm domain and from 0.90 to 0.98 in the 8 – 14 µm domain

Simulations at canopy scale

- 4SAIL canopy model (Verhoef et al., 2007) in the visible – infrared
- Input variables: reflectance and transmittance spectra of fresh and dry *Catalpa* leaves (USGS)

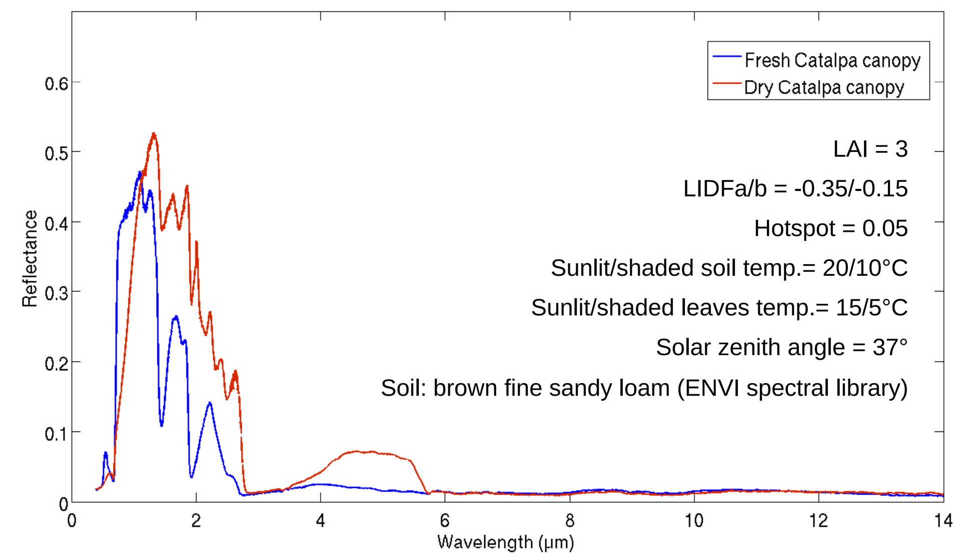

Fig. 2 Simulations of canopy reflectance using 4SAIL

→ Canopy reflectance is sensitive to water content up to 5.7 µm

→ Promising results for remote sensing applications

The *PROSPECT – VISIR* model

PROSPECT is a radiative transfer model simulating leaf directional-hemispherical reflectance and transmittance in the 0.4 – 2.5 µm region as a function of biochemical content (photosynthetic pigments, water and dry matter) and structure anatomy

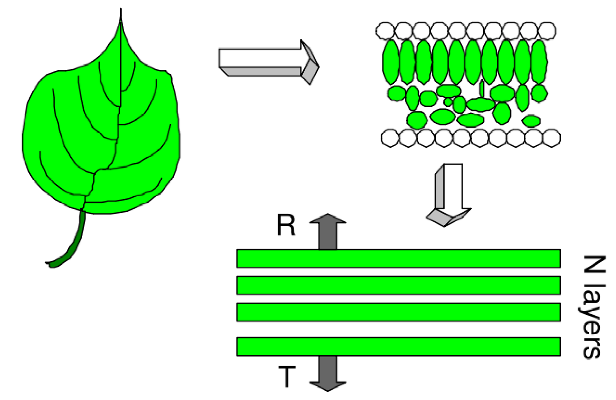

Fig. 3 The PROSPECT model

$$k(\lambda) = \sum_i \left(\frac{C_i}{N} . k_i(\lambda) \right)$$

***Eq. 1** Absorption of one elementary layer as a function of wavelength, biochemical content, specific absorption coefficients and leaf structure parameter*

Parameters:

- Water $k_w(\lambda)$
- Dry matter $k_m(\lambda)$
- Chlorophyll $k_{ab}(\lambda)$
- Carotenoid $k_{car}(\lambda)$

} specific absorptions coefficients

- Refractive index $n(\lambda)$

Variables:

- Water content C_w
- Dry matter content C_m
- Chlorophyll content C_{ab}
- Carotenoid content C_{car}
- Leaf structure parameter *N*

Extension of *PROSPECT* in the 2.5 – 5.7 µm domain: *PROSPECT – VISIR*

Hypothese: no pigment absorption ($k_{ab}(\lambda) = k_{car}(\lambda) = 0$) after 0.8 µm

Purpose: determination of $k_w(\lambda)$, $k_m(\lambda)$ and $n(\lambda)$

Available data: 64 leaf samples (reflectance and transmittance spectra, water and dry matter content)

Calibration method:

1. Determination of *N* by inversion of *PROSPECT* in the near infrared
2. Determination of $k_m(\lambda)$ and $n(\lambda)$ using dry leaves, assuming that C_m, C_w, *N* and $k_w(\lambda)$ are known (we take pure liquid water specific absorption coefficient $k_w(\lambda)$ in the literature)
3. New determination of $k_w(\lambda)$ using the whole dataset, assuming that C_m, C_w, *N*, $k_m(\lambda)$ and $n(\lambda)$ are known

Calibration and validation results

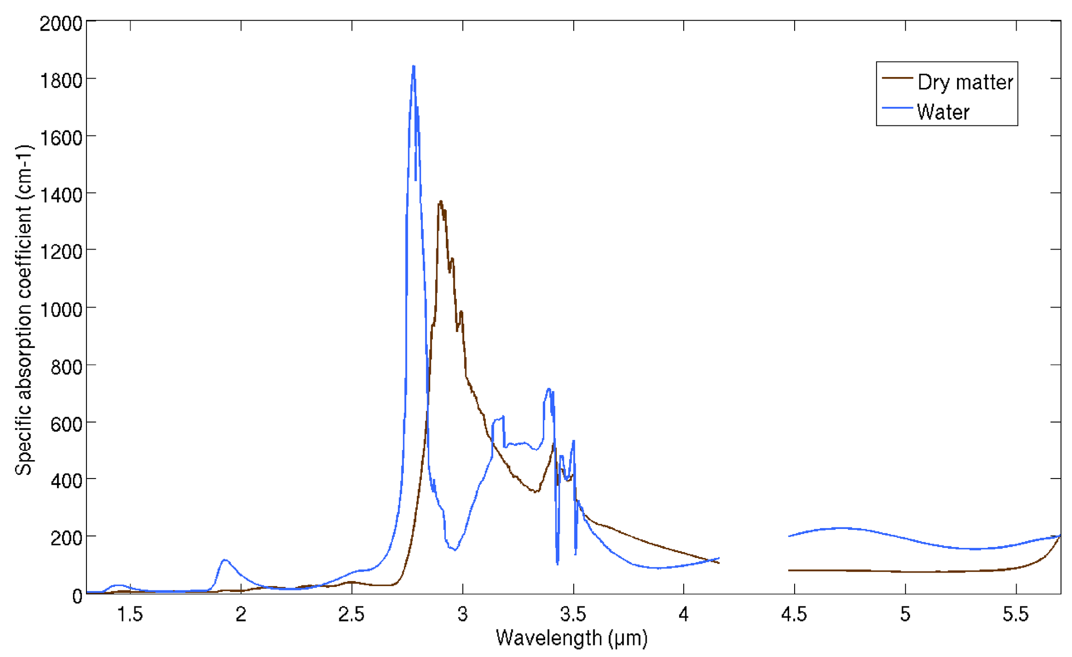

Fig. 4 Calibrated water and dry matter specific absorption coefficients

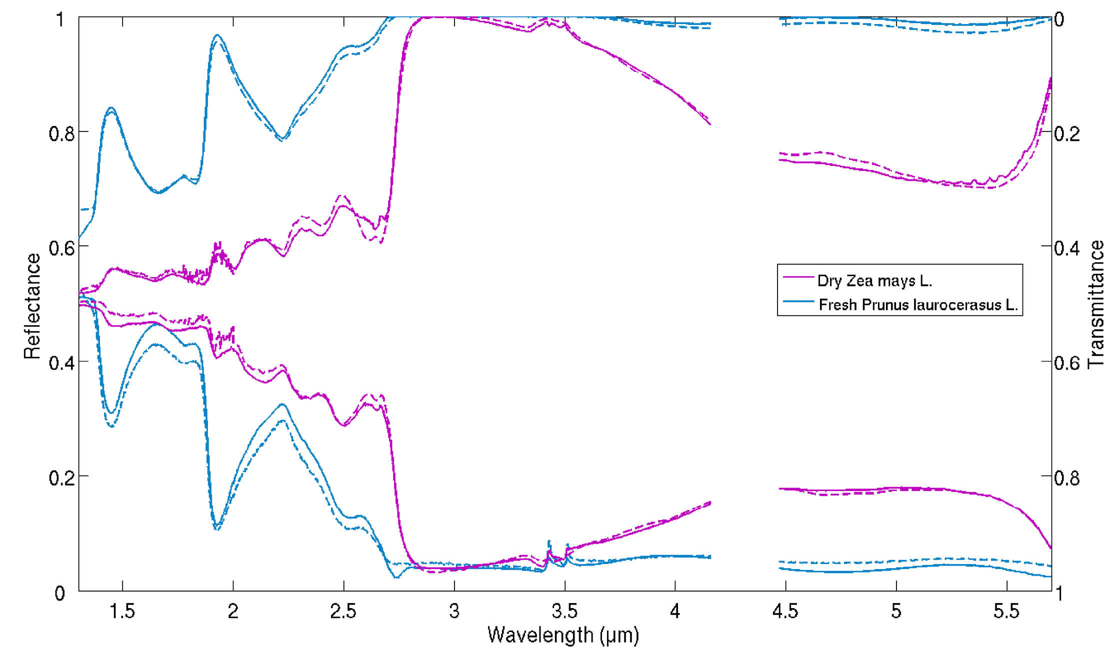

Fig. 5 Inversion of the model on a dry and a fresh leaf
Dashed line: data – plain line: model

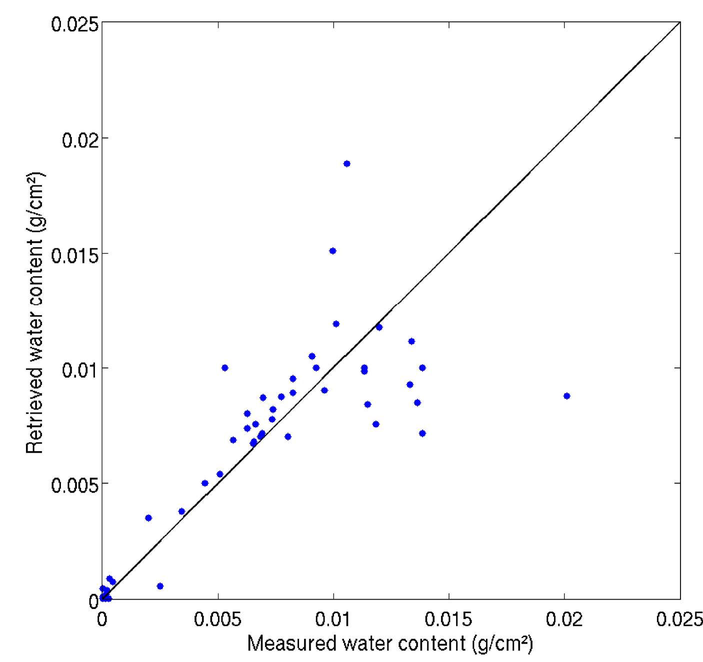

Fig. 6 Retrieved vs measured leaf water content
RMSE=0.0054

(Because of CO_2 absorption in the integrating sphere during ONERA campaign, the 4.16 – 4.47 µm domain is not defined)

Conclusion

- First attempt to model leaf optical properties in the continuous 0.4 – 5.7 µm wavelength range, first model of leaf emissivity
- Future work: extension of the model after 5.7 µm, scaling up these properties to simulate top-of-canopy and top-of-atmosphere radiances
- Improvement of vegetation water content retrieval by remote sensing techniques and Earth's energy budget knowledge

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